Driving Away From Off-Peak Vehicle Charging: The Need for an Evaluation of the Effects of Public Vehicle Charging Infrastructure on PEV Owner Charging Behavior

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ABSTRACT

In response to the increasing availability and ownership of plug-in electric vehicles (PEVs), electric utilities, municipalities, businesses, and other entities have put forth a concerted effort to construct an electric vehicle charging infrastructure built around publicly available electric vehicle charging stations. The goal of this effort has been to increase the utilization and ownership of electric vehicles by providing owners and potential owners with viable options for charging their vehicles in locations other than their home. While the ongoing effort to increase PEV ownership and utilization through the construction of publicly available charging infrastructure is laudable, it also creates an incentive for PEV owners to shift a larger proportion of their charging away from the off-peak periods of low electric demand that are the most desirable from an economic and grid reliability perspective.

Although the short-term implications of increased public charging are likely minimal, a wholesale shift in PEV owner charging behavior away from off-peak periods towards on-peak periods would undermine assumptions about future grid reliability in the face of significant electric vehicle market penetration. To fully understand the potential energy and economic impacts that large shifts in electric vehicle charging behavior could entail, utilities should take steps to evaluate the effects of publicly available vehicle charging infrastructure on their systems. By doing this, utilities will be able to proactively address any future challenges brought about by increased electric demand from vehicle charging.

Introduction

Over the past few years, electric vehicles have become an increasingly available option for drivers. The variety of battery electric and plug-in hybrid vehicle models available to drivers continues to expand in each subsequent model year as more manufacturers make the decision to build electric vehicles. Drivers have responded to this new trend and begun to fill their garages and driveways with vehicles that derive some or all of their "fuel" from the electric grid. As more of the miles driven have become electric, networks of charging infrastructure that allow drivers to plug in and charge away from home have sprung up in cities, at workplaces, along highways, and in all kinds of other places where drivers are likely to recharge their vehicles. These networks are being built by a variety of organizations: private corporations, cities, utilities, businesses, and at least one automaker have all installed charging infrastructure for electric vehicles.

Although public charging still represents a relatively small percentage of all electric vehicle charging, the combination of more electric vehicles on the roads and more publicly available charging infrastructure has led to a steady increase in the proportion of charging that takes place away from drivers' homes. As public charging has increased, so too has on-peak charging. This is not a coincidence. Public charging infrastructure is primarily utilized during the day when drivers are away from home and more likely to overlap with periods of peak demand. To date, the impacts of this trend have been minimal. However, as publicly available charging infrastructure continues to become more widely available to PEV drivers, its utilization rates will increase.

This paper will begin by briefly characterizing PEV plug load and the adequacy of the existing electric grid. Building on this background information, the paper will describe the recent trend of increasing public charging using real-world examples from the EV Project. Following this, the paper will argue that widely available public charging infrastructure has the potential to encourage sub optimal charging behavior that could add to peak demand on electric utilities' systems. Finally, the paper will propose a series of evaluation questions that could lend insight into the long-term impacts of publicly available charging infrastructure.

The paper draws on a variety of sources including PEV owner survey data collected by the California Center for Sustainable Energy (CCSE), regional charging behavior data collected as part of the Department of Energy-supported EV Project, and interview data from interviews conducted with electric vehicle program staff at Puget Sound Energy (PSE), Portland General Electric (PGE), and San Diego Gas and Electric (SDG&E).

Characterizing Electric Vehicle Plug Load

Depending on the type of charger it is plugged into, PEV plug load can range from less than an electric clothes dryer to more than multiple houses combined. Table 1 shows the range of electric vehicle charger loads compared to an electric clothes dryer and a typical home. As the table shows, the type of charger being used to charge a PEV has a major impact on its potential load. The two largest loads in the table, the Level II PEV and DC Level III PEV (highlighted blue), are also representative of the two types of chargers most often deployed as public charging infrastructure.

Table 1: PEV Load Compared to Household Loads

Load Description	Electric Load
Level I PEV	1.5 kW
Electric Clothes Washer	4-5 kW
Whole-House Load (no PEV)	5-7 kW
Level II PEV	7 kW
Level III DC PEV	25-100 kW

Due to their ability to more quickly recharge PEVs, Level II and Level III DC chargers are used almost exclusively in public charging infrastructure deployments. The most notable example of this is the EV Project, a nationwide effort to deploy PEV charging infrastructure supported by the Department of Energy that had installed over 2000 publicly available chargers as of January 2013, all of which were either Level II or Level III DC.

Grid Adequacy in the Face of Electric Vehicles

Although PEVs are relatively large individual electric loads, they are unlikely to bring the existing electric grid crashing down anytime soon. The existing grid is especially adequate from an energy perspective, as demonstrated in a 2010 Pacific Northwest National Laboratories (PNNL) report titled *Impacts Assessment Of Plug-In Hybrid Vehicles On Electric Utilities And Regional U.S. Power Grids Part 1: Technical Analysis*. The authors of the PNNL report demonstrate that the current (2010) electric grid could supply the energy needs of approximately 84 percent of the total U.S. light duty vehicle fleet. For the purpose of the study, the authors assume the total number of vehicles in the light duty vehicle fleet to be 217 million, so 84 percent represents approximately 182 million cars and trucks. Although the authors of the report employ a method of calculating available generating capacity that likely overestimates the capacity of the U.S. electricity grid to supply the energy needs of PEVs, their report demonstrates that the grid could indeed support a large number of PEVs while maintaining its current reliability (Kintner-Meyer 2010).

The grid also appears to be quite able to support a large number of PEVs from a demand perspective. Looking at a hypothetical "nightmare scenario" of lots of PEVs plugging in simultaneously at the exact moment of 2012 peak summer demand on the California Independent System Operator's (CAISO) grid, the grid resources outlined in the CAISO 2012 Summer Loads and Resources Assessment, could support roughly one million PEVs charging at 7 kW (CAISO 2012).

The impacts of PEV demand are much more likely to be felt at the neighborhood distribution system level as opposed to the system-wide level. Although neighborhood transformers are typically sized to accommodate periods of peak demand, the addition of multiple PEVs and chargers on a single transformer can cause the transformer to fail prematurely. However, according to PEV program staff at both Southern California Edison (SCE), and Puget Sound Energy (PSE), this is not a significant issue. During an interview for this paper, Patrick Leslie, Emerging Technologies Manager at (PSE), said that, according to PSE's calculations, the revenue benefit of new PEV load on their system far exceeds the cost of the infrastructure needed to support it (Leslie 2013).

Embracing Off-Peak

Although the hypothetical scenario of many PEVs charging simultaneously during periods of peak demand appears to be something the existing grid could support, on-peak charging on a large scale is generally considered to be undesirable from an economic and grid reliability perspective. On the economic side of things, on-peak charging of PEVs, like any other form of incremental peak demand, is inefficient from a cost perspective because the marginal kW and kWh during periods of peak demand are typically supplied by some form of gas combustion turbine, or "peaker plant," which tend to have higher operating costs and lower efficiencies than baseload generation resources such as nuclear, coal, hydroelectric, or combined-cycle gas plants.

Large numbers of PEVs charging during periods of peak demand could also adversely impact grid reliability in a number of ways depending on the region in which they are plugged in. While states like California have reserve margins that could comfortably accommodate a moderate number of PEVs charging during peak periods, states such as Texas, with its smaller reserve margins, could see a measureable decrease in their grid reliability if large numbers of PEVs began to charge during peak periods. Additionally, although the aggregate system impacts of on-peak PEV charging in a given service territory may be small, the impacts to distribution infrastructure at the neighborhood level can be meaningful if equipment such as transformers are not upgraded to accommodate the incremental demand of PEVs.

For these reasons, a number of utilities offer their customers with PEVs the option of time-of-use (TOU) rate plans. Under these rate plans, customers typically pay a different price for each kWh depending on the time of day that they use electricity. Although there are a variety of TOU rate plans, a common TOU rate plan often has two time periods: on-peak and off-peak. During the peak period, the customer pays a higher price for each kWh they use, while during the off-peak period, the price per kWh is lower. To accommodate normal, non-PEV electricity use that occurs during the day (air conditioning, lighting, etc.), a number of utilities offer their customers the ability to sub meter their electric vehicle charger. Under this scenario, only the kWh used to charge a customer's PEV are subject to the TOU rate, while other household electricity consumption is billed under the utility's normal rate plan.

Based on the charging behavior of drivers enrolled in the EV Project, TOU rates appear to be an effective incentive for motivating drivers to charge their PEVs off peak. An example of this is shown in Figure 1, which compares PEV demand profiles from three EV Project cities: San Francisco, San Diego, and Nashville. The utilities serving the majority of customers in San Francisco and San Diego, PG&E and SDG&E, both offer their customers with PEVs TOU rate plans. Conversely, Nashville Electric Service, the electric utility serving Nashville, does not offer its customers a TOU rate option. As the figure illustrates, the

PEV demand in both San Francisco and San Diego occurs primarily during the off-peak hours of midnight to 5am while the peak PEV demand in Nashville occurs between about 5pm and 10pm.

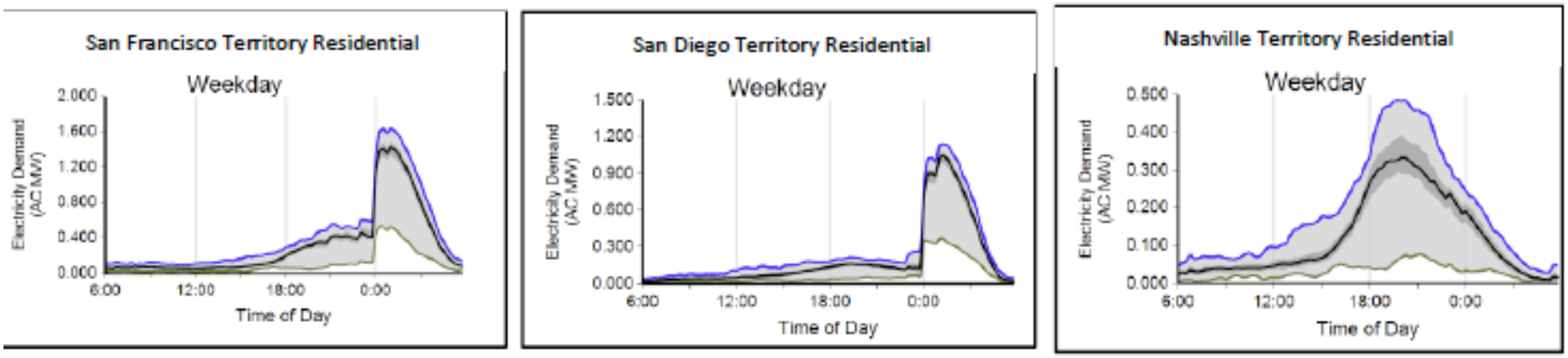

Figure 1: PEV Demand Profiles in San Francisco, San Diego, and Nashville (EV Project 2013).

Public Charging

The number of public PEV chargers and the number of drivers using them has increased steadily since the end of 2011. As Figure 2 demonstrates, the number of publicly available PEV chargers (EVSE), has grown each quarter in every EV Project region except for Nashville.

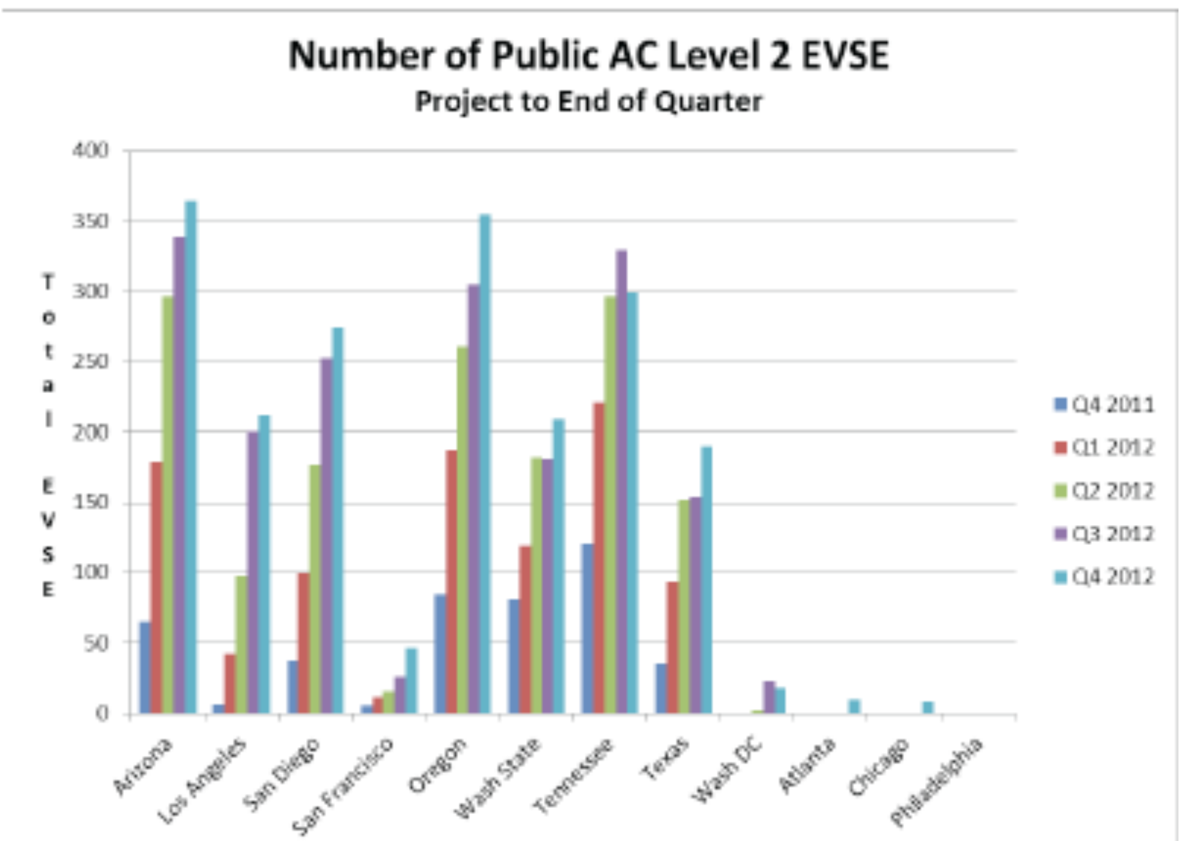

Figure 2: Number of EV Project Public PEV Chargers Q4 2011-Q4 2012 (EV Project 2013).

Similarly, as Figure 3 shows, the percentage of total charging events that occur away from home has increased steadily since the end of 2011. The notable exception is the decrease that occurs between Q3 2012 and Q4 2012. This decrease is likely a result of the holidays that occur in the fourth quarter of 2012, including Thanksgiving, Christmas, and Hanukkah, where drivers are most likely not engaging in their normal commutes and may remain at home more than they would during other times of the year.

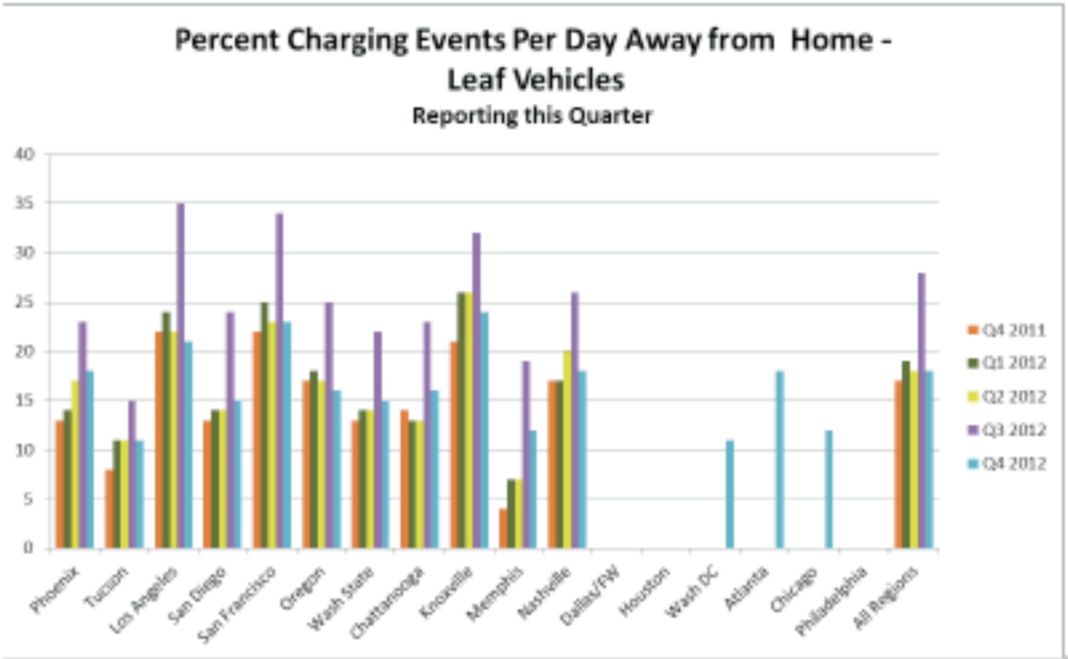

Figure 3: Percent of Total EV Project Charging Events Per Day Away From Home (Nissan Leafs) (EV Project 2013).

While public charging currently represents between around 10 and 20 percent of total EV Project charge events, the load profiles from a variety of public chargers in the EV Project illustrate how public charging demand is much more likely to overlap with periods of system-wide peak demand than home-based charging. Figure 4 shows the aggregate demand from all of the publicly availably chargers in the EV Project network. As Figure 4 demonstrates, the bulk of the demand from public chargers in the EV Project occurs between 9am and 6pm, a range of time within which many system peaks fall. This contrasts with the typical home-based, TOU rate load profile, which, as the San Francisco and San Diego regions in Figure 1illustrate, falls well outside the range of peak system hours.

In addition to overlapping with peak system hours in a way that home-based PEV charging does not, the individual charger load impact of public charging can also be significantly greater than home charging. The reason for this is Level III DC Chargers. As shown in Table 1, Level III DC Chargers can draw anywhere from 25 kW to 100 kW, depending on their configuration, compared to the 7 kW maximum of a home charger. As a result of their large individual loads, Level III DC Chargers can create “mini peaks” on local grids. An example of this is shown in Figure 5, which compares PEV charging demand for the Portland General Electric (PGE) and Seattle City Light (SCL) grids in the second and third quarters of 2012. In the second quarter (right side of Figure 5), there were not any Level III DC chargers in either PGE or SCL’s service territory. Level III DC chargers were installed in both territories in the third quarter of 2012. As the load profiles demonstrate, the addition and use of Level III DC chargers in the third quarter created significantly more variable or “choppy” demand on both systems.

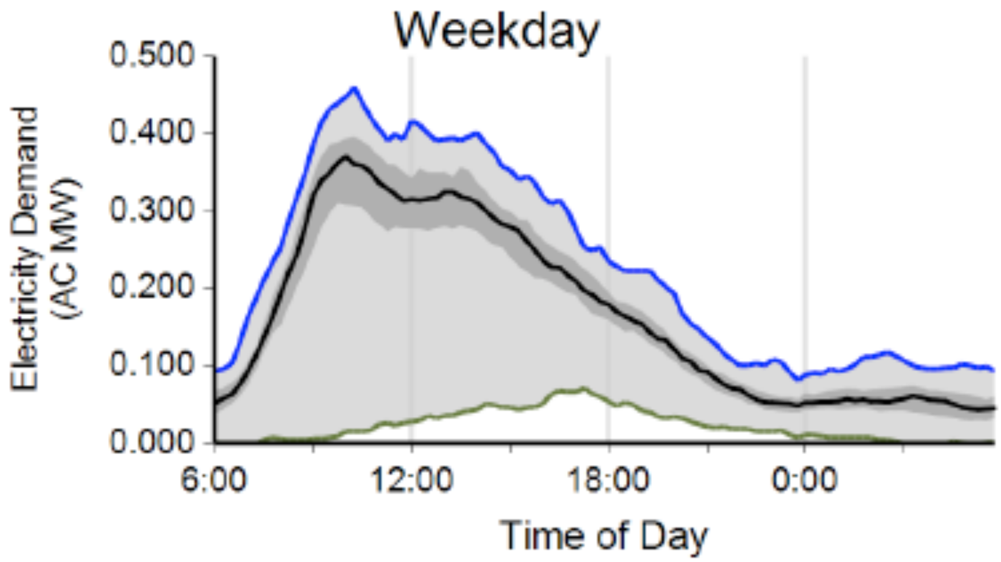

Figure 4: EV Project Publicly Available Level 2 Charger Demand (All Regions Q4) (EV Project 2013).

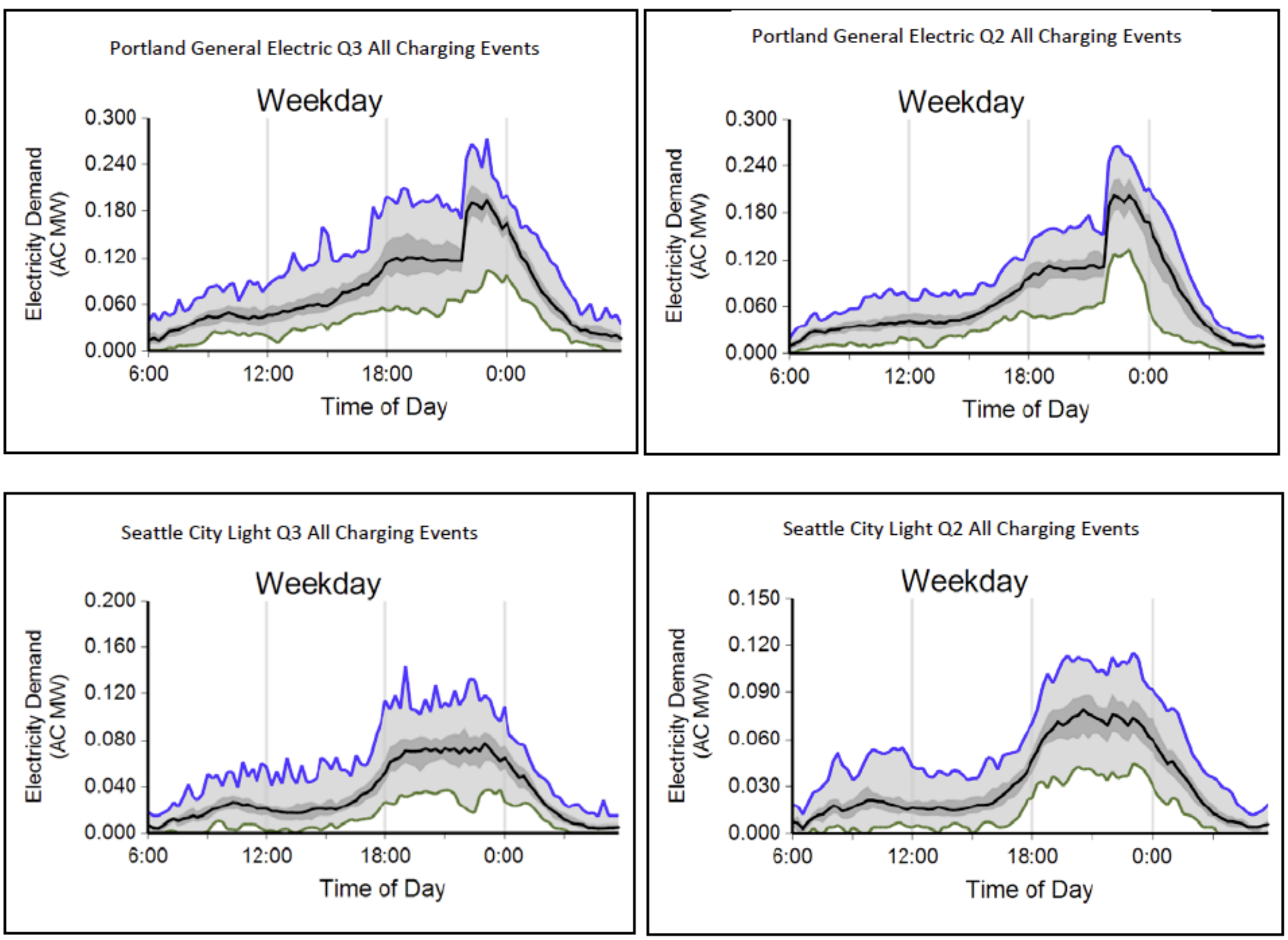

Figure 5: Level III DC Charger Impacts (EV Project 2013).

Bad Charging Habits

While public charging infrastructure is not going to bring down the grid tomorrow, it does have the potential to sow the seeds of bad charging behavior on the part of drivers. As shown in Figure 1, TOU rates are an effective method of encouraging drivers to charge during off-peak periods. However, the effectiveness of TOU rates in modifying drivers' charging behavior is dependent on drivers receiving a clear and meaningful price signal. In the case of the drivers in San Diego and San Francisco in Figure 1, this price signal is sent and received directly via drivers' electric rates. Drivers in those cities who are enrolled in the TOU rate option for their PEVs understand that charging during non-off-peak hours will cost them significantly more than charging during off-peak hours. Consequently, these drivers primarily charge their PEVs during off-peak hours and thus avoid the higher electric rates.

In the case of public charging, there is not a comparably direct price signal to discourage drivers from charging during periods of high demand. One of the primary reasons for this is that drivers charging at public charging stations typically do not pay for their charge on a per kWh basis. Many public charging stations are free to use, and those that do charge a fee typically operate on a pay-per-charge or pay-per-minute basis. In each case, the driver is not given a direct price signal to encourage them to charge off-peak. The result of this is that the majority of drivers who charge their vehicles at public charging stations are effectively insulated from the true cost of charging during periods of peak demand.

An additional, compounding factor in the public charging equation is the fact that a primary goal of public charging stations is to provide a reliable way for drivers to extend the effective range of their PEVs in the relatively small time windows between destinations. Given this goal, it would be counterproductive to attempt to control charging demand using any form of "Smart Charging" that varies the rate of energy delivered to a charging PEVs depending on factors such as time or grid conditions.

The Opportunity for Evaluation

Although the increasing availability of public charging infrastructure does not represent any kind of imminent threat to the stability of electric grids, there remains a large amount of uncertainty surrounding how drivers will interact with public charging infrastructure as it becomes more available and PEVs become more prevalent. This uncertainty is an opportunity for evaluation. While a fair amount of research has been devoted to how drivers charge their PEVs at home and the effects of price signals on their charging behavior, there is very little existing research specifically targeted at PEV drivers' interactions with public charging infrastructure.

As a larger proportion of PEV charging continues to shift to public charging infrastructure (and likely to on-peak hours), the importance of understanding how drivers interact with public infrastructure will increase. For those utilities with large concentrations of PEVs on their systems, understanding how increasingly available public charging infrastructure affects the charging behavior of PEV drivers will enable them to proactively engage PEV stakeholders and plan for any possible shifts in charging behavior. In support of this effort, the following are a series of potential evaluation questions that could lend insight into the changing interactions between PEV drivers and public charging infrastructure:

- Does the availability of public charging infrastructure affect drivers' charging behavior at home?
- Are PEV drivers willing to pay a premium (compared to home charging) to use public charging infrastructure?
- What kind of price signal will be needed to shift public charging away from peak periods?
- What are the viable options for sending a meaningful price signal to drivers using public charging infrastructure?
- Are drivers receptive to limiting their charging at public chargers during periods of peak demand?

- In cases where public charging is provided by a third party, how can utilities effectively engage with drivers?

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